

# SOHO Illuminates the Sun

The closest star to Earth, 150,000,000 km (93 million miles) away, the Sun produces the energy that drives our ecosystem, making it the source of all life on Earth. The Sun is a ball of plasma (super heated gases) seething and moving at extreme temperatures. It produces the **solar wind**, a stream of million degree gases which flows out from the Sun at hundreds of kilometers a second. The solar wind interacts with Earth's magnetic field to produce the awe inspiring aurora (also known as the Northern or Southern lights). Solar wind disturbances can also disrupt communication signals and cause power outages. If we could detect and understand the sources of the solar wind, we could prepare for and reduce its negative effects.

The **Solar and Heliospheric Observatory** (SOHO), launched in late 1995, is a spacecraft that is increasing our understanding of the Sun and solar wind. It was designed to explore a number of questions:

## What is it like inside the Sun?

Hot? No question there: but just how hot is it? We think that the core of the Sun is a 15 million degree C soup of electrons and protons stripped from the hydrogen atoms that make up 90 percent of the Sun. Every second, thousands of protons in the Sun's core collide with other protons to produce helium nuclei in a fusion reaction that releases energy. Just outside the core, energy moves outward via radiation. Closer to the surface, the energy moves out via convection - hot gases rise, cool, and sink back down again.

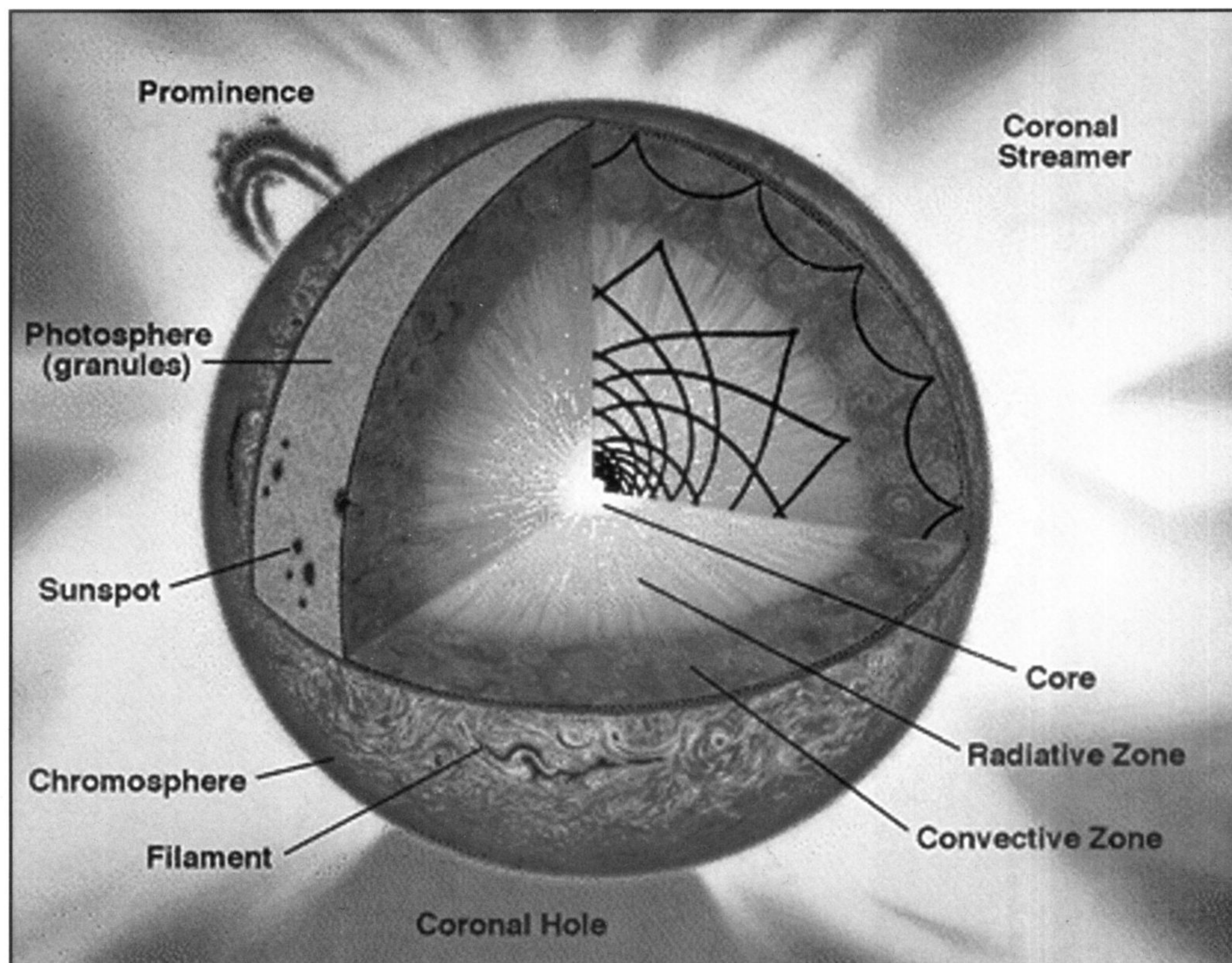
As these masses of gas move, they push off of each other causing "Sun-quakes." These make the material in the Sun vibrate or, "ring like a bell," at certain harmonic frequencies. The study of the movement of the Sun's surface is called helioseismology (as the study of movements of Earth's surface is called, simply, "seismology"). Helioseismology helps us determine the Sun's internal structure, the temperatures, densities, proportions of different elements, and the processes occurring at different locations underneath the Sun's surface. Dopplergrams (see image to the right) can detect and identify the various internal sound waves the Sun produces.

## Why is the corona so hot?

The layer of the Sun's atmosphere we usually see in visible wavelengths of light is called the **photosphere**. The photosphere is at about 5500° C. The **corona** is the outermost layer outside the Sun's atmosphere. Scientists would expect that the Sun would be cooler farther from the heat source in the core. However, this reasoning seems to break down when we look at the Sun's corona. The corona is over a million degrees C! Scientists do not know why.

From Earth the corona is best seen during a solar eclipse. From space, however, we do not have to wait so long. Without the scattering of light by the Earth's atmosphere we can create an artificial eclipse using an instrument called a coronagraph. This blocks out the bright disk of the Sun with a corresponding black disc in the camera's center so that we can see and study the corona in visible light scattered off the coronal electrons.

Because the corona is so hot, it also emits light in ultraviolet wavelengths. These wavelengths cannot get through the Earth's atmosphere, but we can see them using the SOHO satellite in space.



*This drawing shows the major features of the Sun. The Sun actually consists of 90% hydrogen and a mixture of other gases. In diameter, it is over 100 times bigger than the Earth.*



### What accelerates the solar wind?

The corona is constantly expanding into space to form the solar wind. The solar wind particles flow out past the farthest planets to form the realm we call the **heliosphere**. Sometimes the wind blows out steadily, but at times the Sun ejects large magnetic field structures called Coronal Mass Ejections (CMEs). [See the photo series on the other side] When the material from CMEs reaches Earth, it can cause pretty effects like the aurora or potentially disruptive effects like power outages in cities near the magnetic poles.

SOHO seeks to study the solar wind both by studying conditions at its source, the corona, and by measuring the wind's speed and composition as it passes the spacecraft.

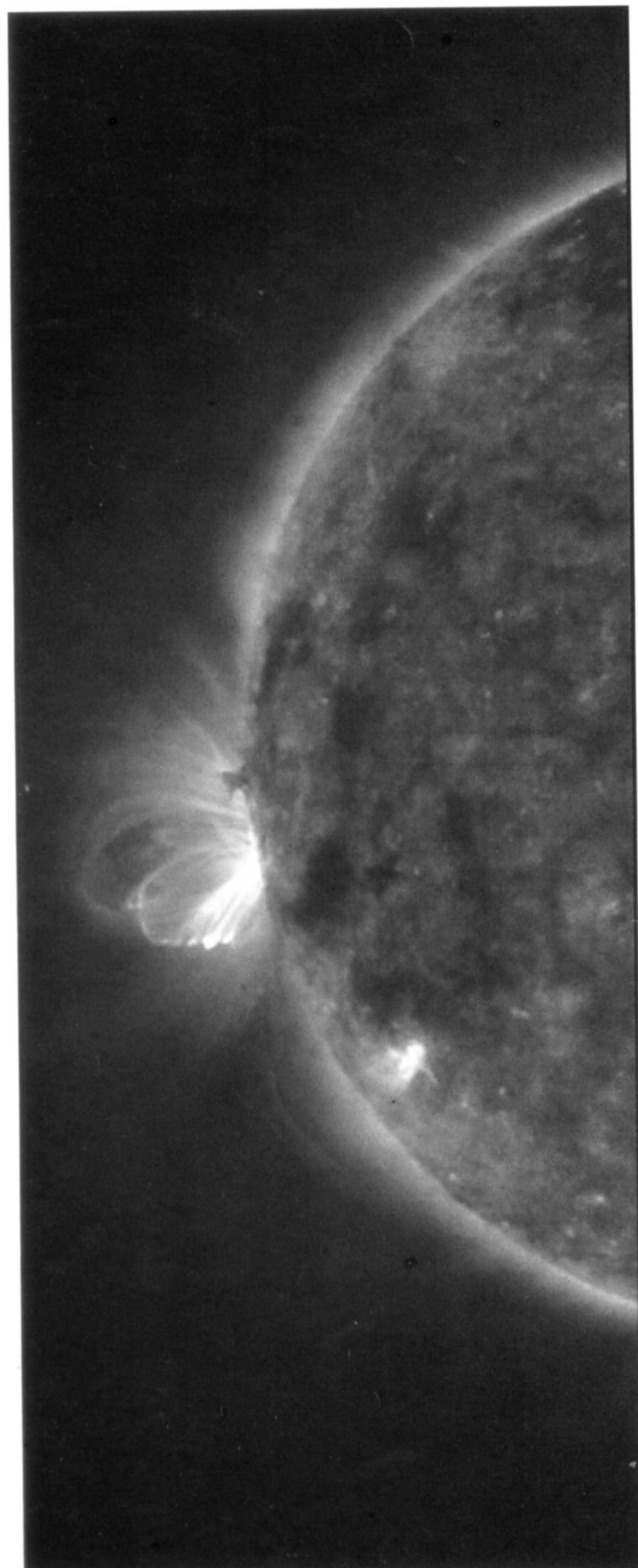
### How is the Sun's magnetic field created and structured?

The Sun's magnetic field is generated by plasma motions below the Sun's surface and extends out to shape and control the solar atmosphere and the entire heliosphere. Understanding the magnetic field is key to understanding the solar wind, heating of the corona, and solar activity such as CMEs, sunspots, and flares. Solar activity increases and decreases in approximately an eleven year cycle. SOHO was launched during the activity minimum and its observations have shown that the Sun is much more active than expected during the solar minimum.

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## The Sun's Atmosphere

In these images of the corona we can see the effects of the magnetic field which shapes the Sun's atmosphere. The magnetic field creates the loops (below left) and other structures such as the ray-like plumes (below right) in the corona, as well as the sunspots we see in the photosphere. Scientists think the magnetic field is important to understanding coronal heating and the solar wind, but do not yet know exactly how.

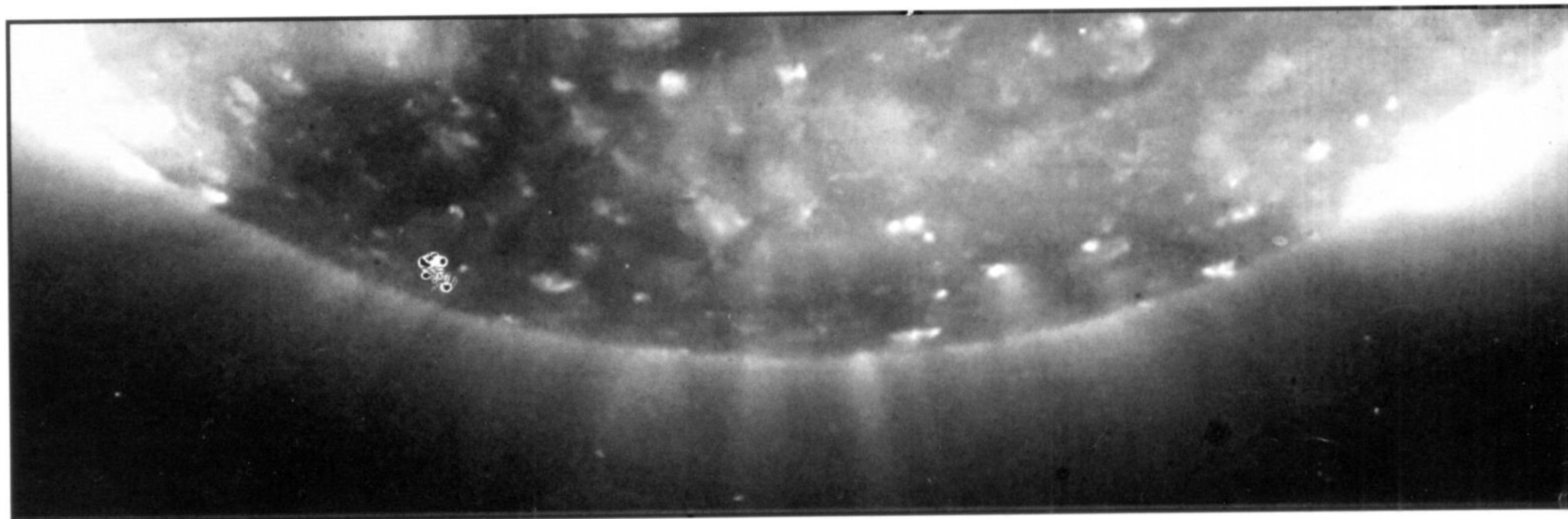


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The ultraviolet image at left shows a **loop** in which the magnetic field can be seen circling back towards the Sun, trapping hot gas.

The corona is shown in visible light in the SOHO coronagraph image above. This image is actually a composite image taken by two coronagraphs, each with a different sized occulting disk. A coronagraph blocks out the light from the bright inner part of the Sun so that we can see its corona. The bright circle in the center represents the location of the Sun's disk.

*The ultraviolet image below reveals structures known as solar plumes, which extend from the polar regions out into the solar system. Hot gas flows along these structures into the solar wind.*



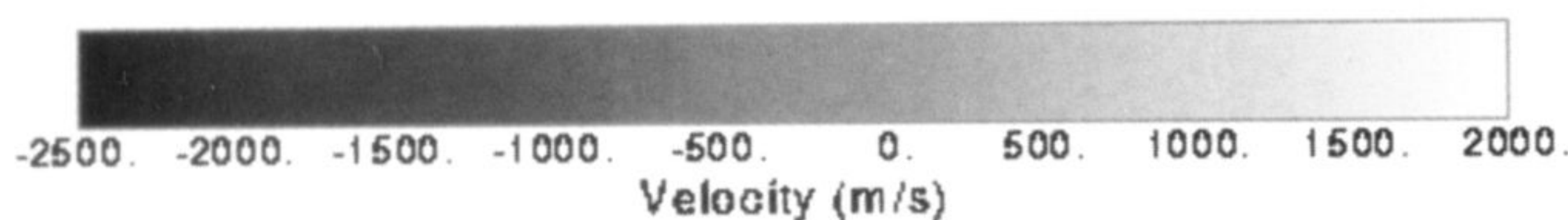
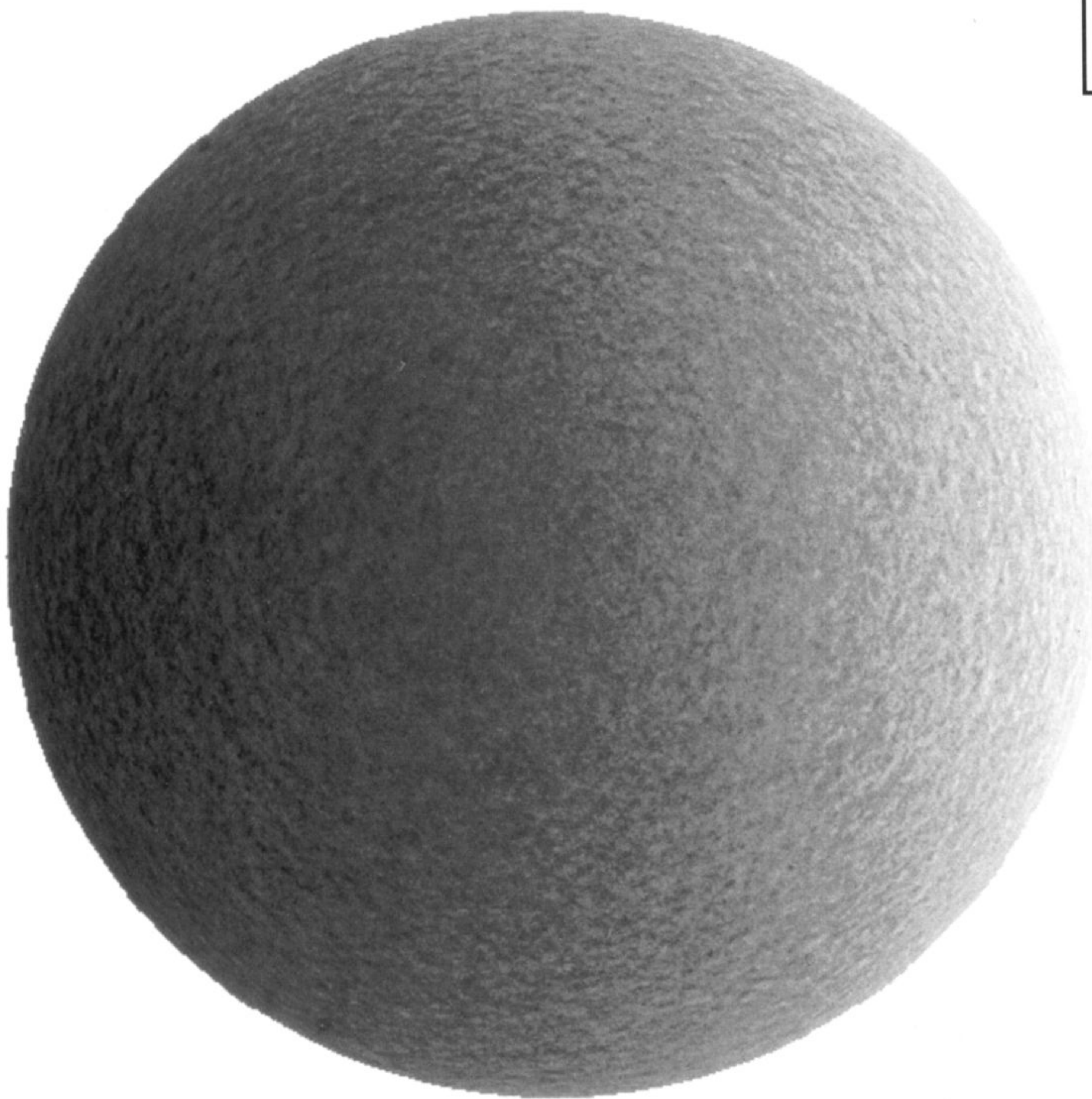
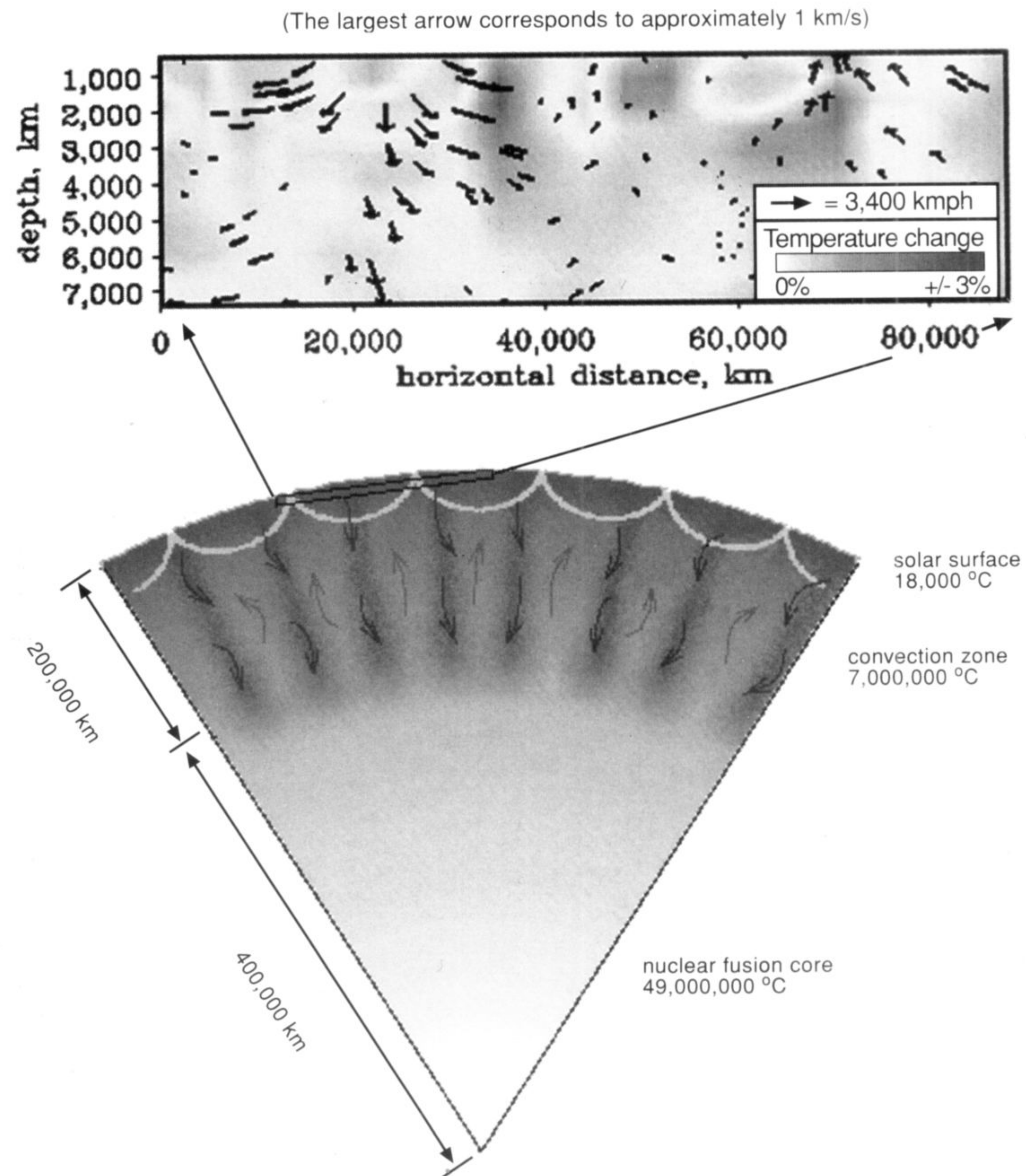


## At and Below the Sun's Surface

In the outer layers of the Sun hot plasma rises, cools, and sinks back down again. This process, called **convection**, forms pancake-shaped cells of rising and falling material. Helioseismology data from SOHO allows us to map these motions underneath the Sun's surface.

The map to the right shows the calculated velocity and temperature below the surface. These measurements give us the first clear picture of convection immediately below the surface of a star – possible only because the SOHO spacecraft (at far right), free of the distortions of Earth's atmosphere and the interruptions of night, is able to extend our measurements of the Sun's surface motions to scales rarely obtainable from Earth.

### Convective Flows Below the Sun's Surface



SOI / MDI

Stanford Lockheed Institute for Space Research

This Dopplergram gives us information about the motion of materials towards and away from us. Here we can see the rotation of the Sun as the left side (darker) rotates towards us and the right side (lighter) turns away. In addition, we see the motions of numerous "small" blobs of gas on the Sun's surface as they rise and fall: each blob is about the size of Earth. Studying their motions can tell us more about the Sun's interior.



## ACTIVITY: Resonance Rings

*Description:* Different sized rings demonstrate the concept of resonant frequencies.

*Objective:* To show how atoms and ions in the Sun's atmosphere absorb energy through resonance and how we can understand the Sun's interior by studying its resonant frequencies.

*Materials:* Used lightweight file folders, cardboard sheet about 20 X 30 cm, masking tape, scissors.

*Procedure:*

1. Cut two strips of paper from used file folders. Each strip should be 3 cm wide. Make the strips approximately 35 and 40 cm long.
2. Curl each strip into a cylinder and tape the ends together.
3. Tape the cylinders to the cardboard as shown in the diagram. If the ring has a crease from the file folder, the crease should be at the bottom.
4. Holding the cardboard, slowly shake it back and forth and observe what happens when you gradually increase the frequency of the shaking.

*Discussion:*

All objects have natural frequencies at which they vibrate. When the frequency of the shaking matches the natural frequency of one of the rings in this activity, it begins to vibrate more than the rest. In other words, some of the energy in the shaking is absorbed by that ring. This effect is called **resonance**. Resonance takes place when the energy of the right frequency (or multiples of the right frequency) is added to an object, causing it to vibrate. When energy from electromagnetic radiation passes through the Sun's corona, it is absorbed at certain wavelengths which match the natural frequencies of atoms and ions in the corona. This leads to dark lines (called absorption lines) in the Sun's spectrum at the frequencies of light absorbed.

Sometimes the ions absorb energy through other means, such as colliding with other ions. In this case the ions may give off their excess energy at particular resonance frequencies, resulting in bright lines at those frequencies in their spectra (these are called emission lines). Both absorption and emission lines can be used to study the ions in the Sun's atmosphere, because each ion has its own unique set of resonance energies.

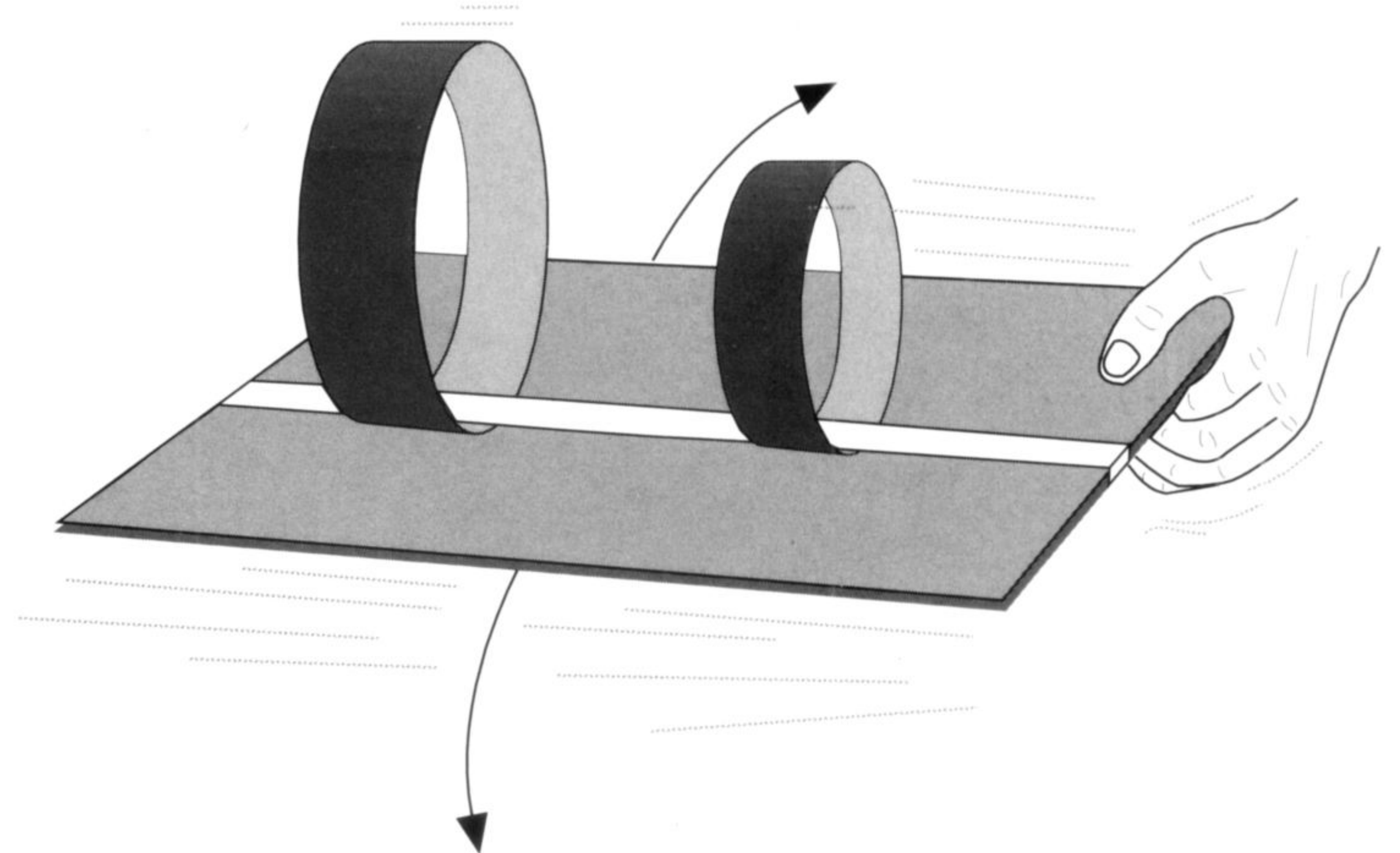
Resonance can also magnify sound waves that travel through the Sun, making it important in the study of the Sun's interior. The study of these waves is called helioseismology. The resonant frequencies are determined by the material, temperature, and density of the plasma through which the waves pass. Thus, by observing the resonant frequencies of the Sun, we can determine the structure below the surface.

*For Further Research:*

Investigate the natural frequencies of various objects such as bells, wine goblets, and tuning forks. If you have an oscilloscope, use it to convert the sounds into wave forms.

Why has the playing of the song "Louie, Louie" been banned at several college football stadiums? Why do marching soldiers crossing a bridge "break cadence"?

Use a prism or diffraction grating to look at various light sources, including an incandescent light bulb, a fluorescent light, neon lights, and street lights. Do NOT use one to look directly at the Sun!



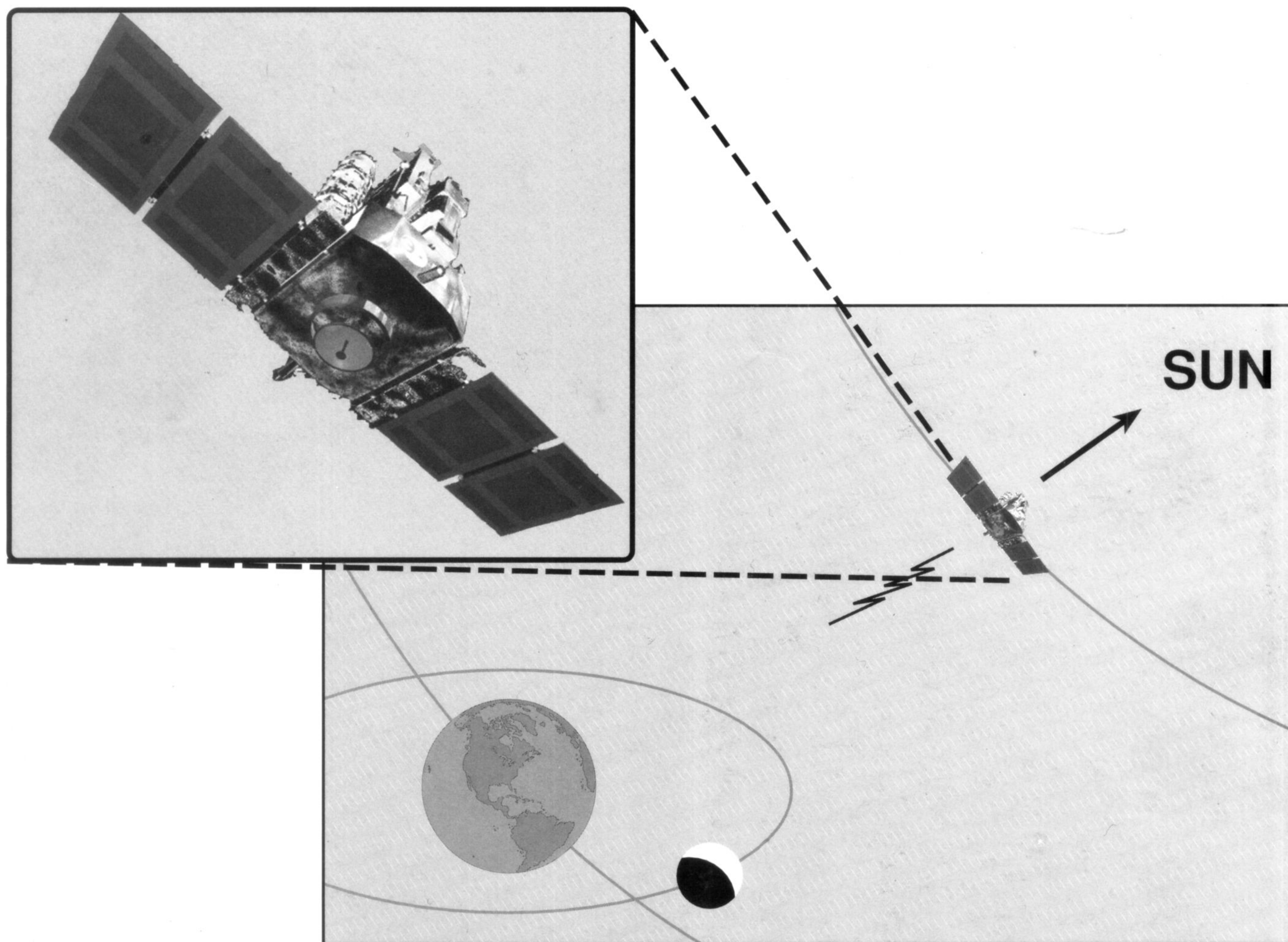


## Solar and Heliospheric Observatory (SOHO)

The Solar and Heliospheric Observatory (SOHO), is a sophisticated spacecraft built and run by the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA). Many other institutions in the U.S. and Europe were involved with the development and operation of the 12 instruments on board. SOHO, launched in December 1995, will observe the Sun and the solar wind for at least two years.

SOHO is one of ESA and NASA's most ambitious projects for the 1990's. It will help us to understand the interactions between the Sun and Earth's environment better than has been possible to date. It may enable scientists to solve some of the most perplexing riddles about the Sun, including the physical conditions of the solar interior, the heating of the solar corona, and the acceleration of the solar wind. It is giving solar physicists their first long-term, uninterrupted view of the mysterious star that we call the Sun.

That view of the Sun is achieved by operating SOHO from a permanent vantage point 1.5 million kilometers (900,000 miles) toward the Sun in a halo orbit around the first Lagrangian point ( $L_1$ ), where the Sun's and Earth's gravitational forces are equal. This location offers a new advantage: most previous solar observatories orbited the Earth, which caused observations to be periodically interrupted when our planet 'eclipsed' the Sun.



*The SOHO spacecraft (above) is shown with its solar panels extended. The 12 instruments on board gather data which tells us about the inside of the Sun, activity on the Sun's surface, the Sun's atmosphere, and its effects on Earth's environment. The illustration shows its position in orbit about 1.5 million kilometers (almost 1 million miles) sunward of the Earth.*



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Apart from live mission coverage, regular NASA Television programming includes a News Video File from noon to 1:00 pm, a NASA History File from 1:00 to 2:00 pm, and an Education File from 2:00 to 3:00 pm (all times Eastern). This sequence is repeated at 3:00 pm, 6:00 pm, and 9:00 pm, Monday through Friday. The NTV Education File features programming for teachers and students on science, mathematics, and technology, including the NASA. . . *On the Cutting Edge* Education Satellite Videoconference Series. The videoconferences include NASA scientists, astronauts, and education specialists presenting aeronautics and Earth & space science topics of interest to teachers and students of grades 5-12. The series is free to registered educational institutions. The videoconferences and all NASA Television programming may be videotaped for later use.

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**How to Access NASA's Education Materials and Services, EP-1996-11-345-HQ** This brochure serves as a guide to accessing a variety of NASA materials and services for educators. Copies are available through the TRC network, or electronically via NASA Spacelink.

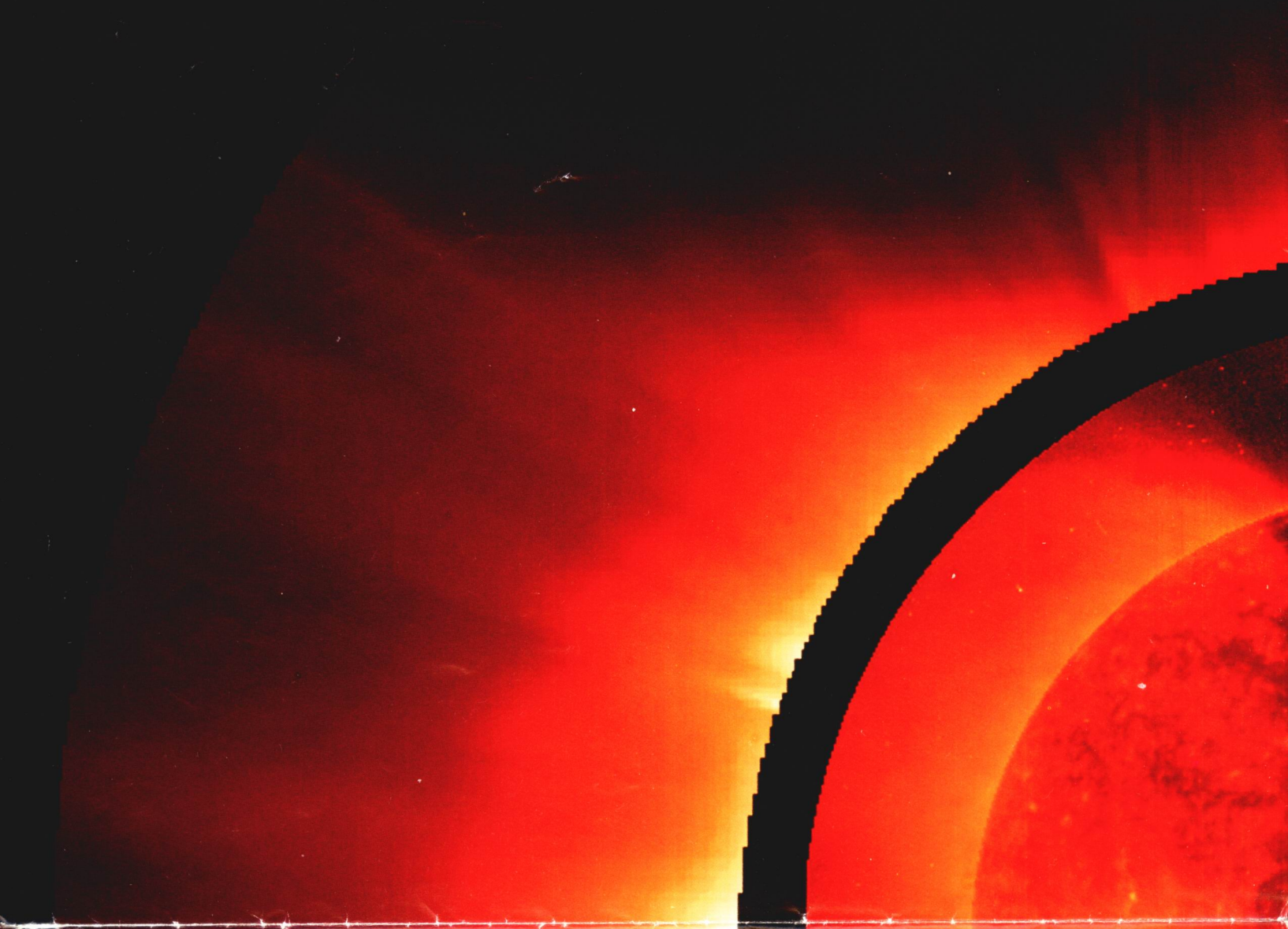
To follow SOHO's progress and to find links to other solar sites, please visit our web sites at: <http://sohowww.nascom.nasa.gov/> and <http://sohowww.nascom.nasa.gov/explore/>

You can E-mail us at [letters@sohops.gsfc.nasa.gov](mailto:letters@sohops.gsfc.nasa.gov), or write us at: Explore, Code 682.3, NASA/GSFC, Greenbelt, MD 20771.

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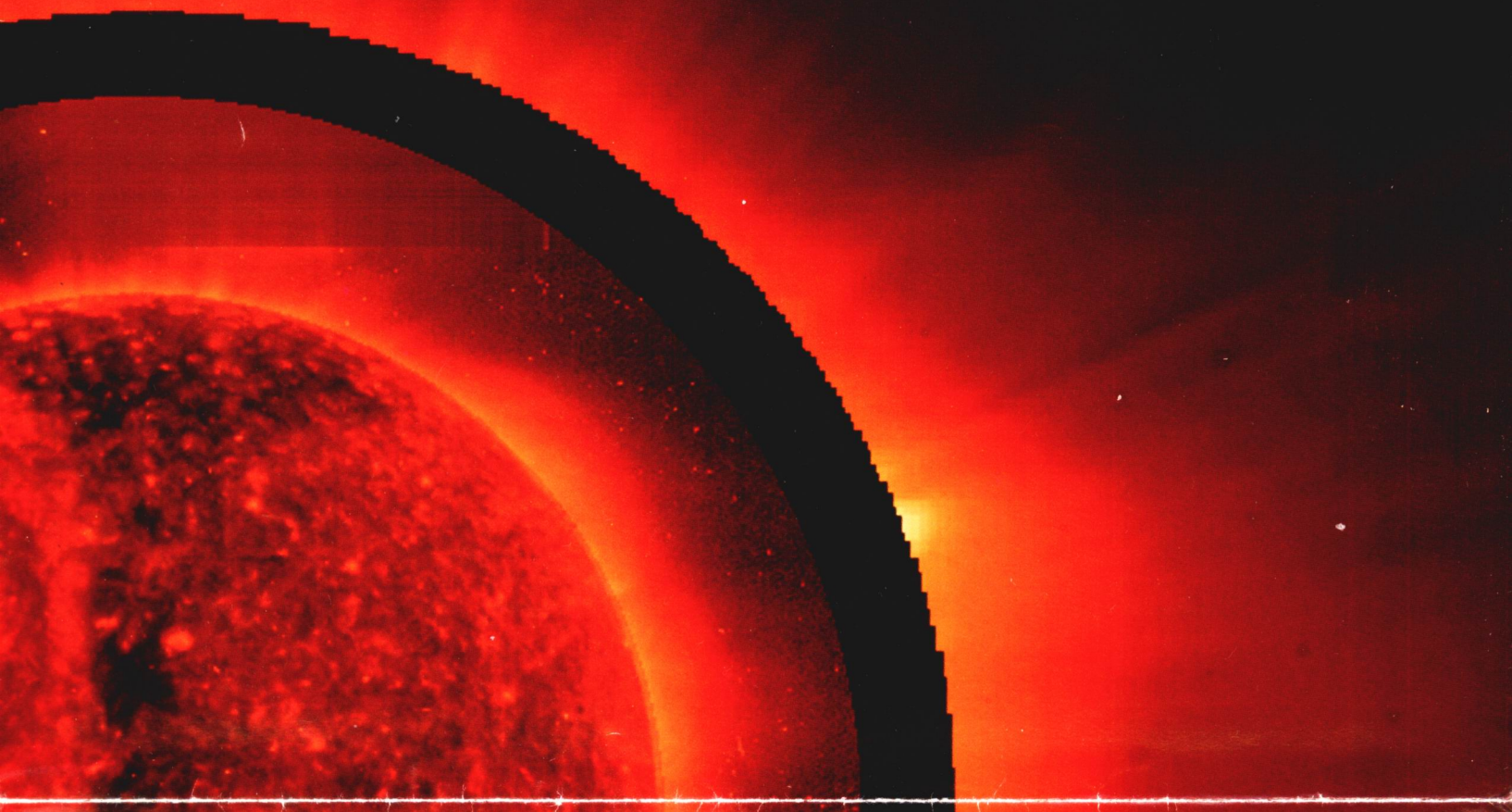
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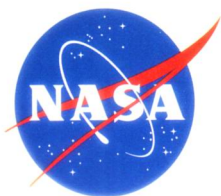


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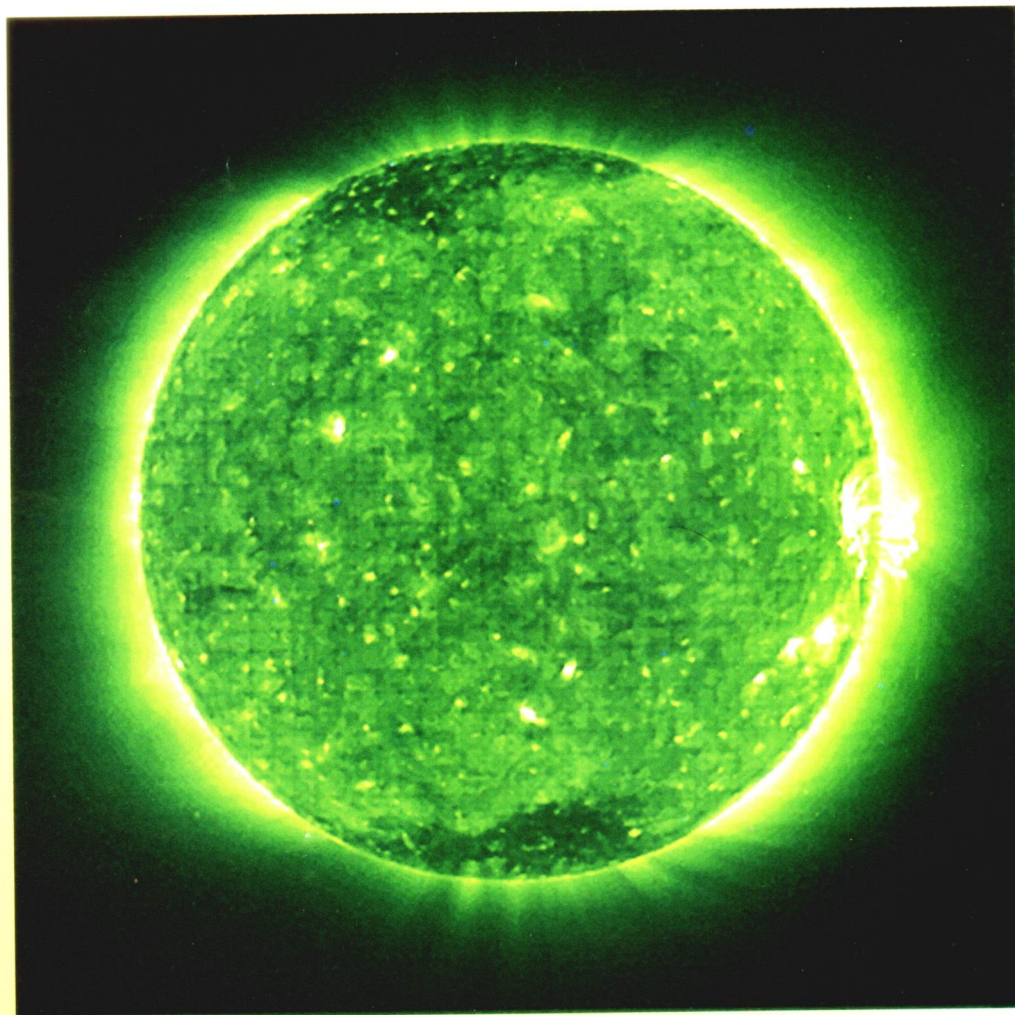
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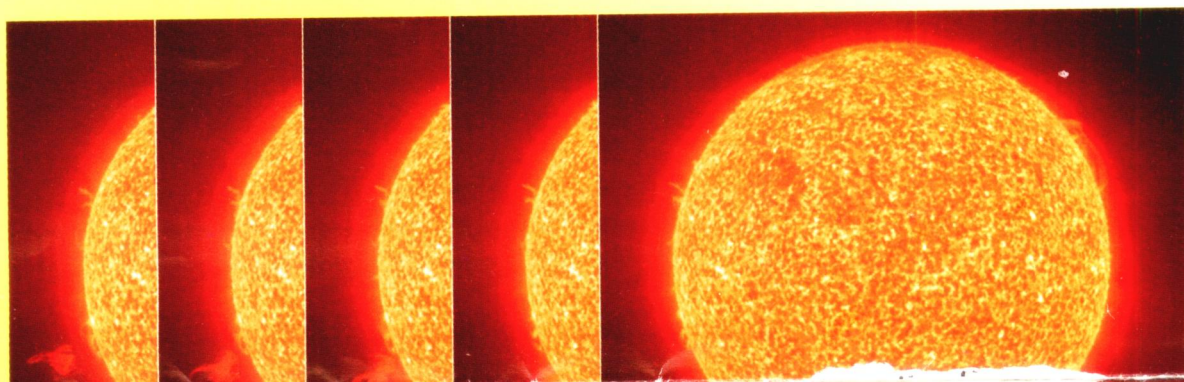




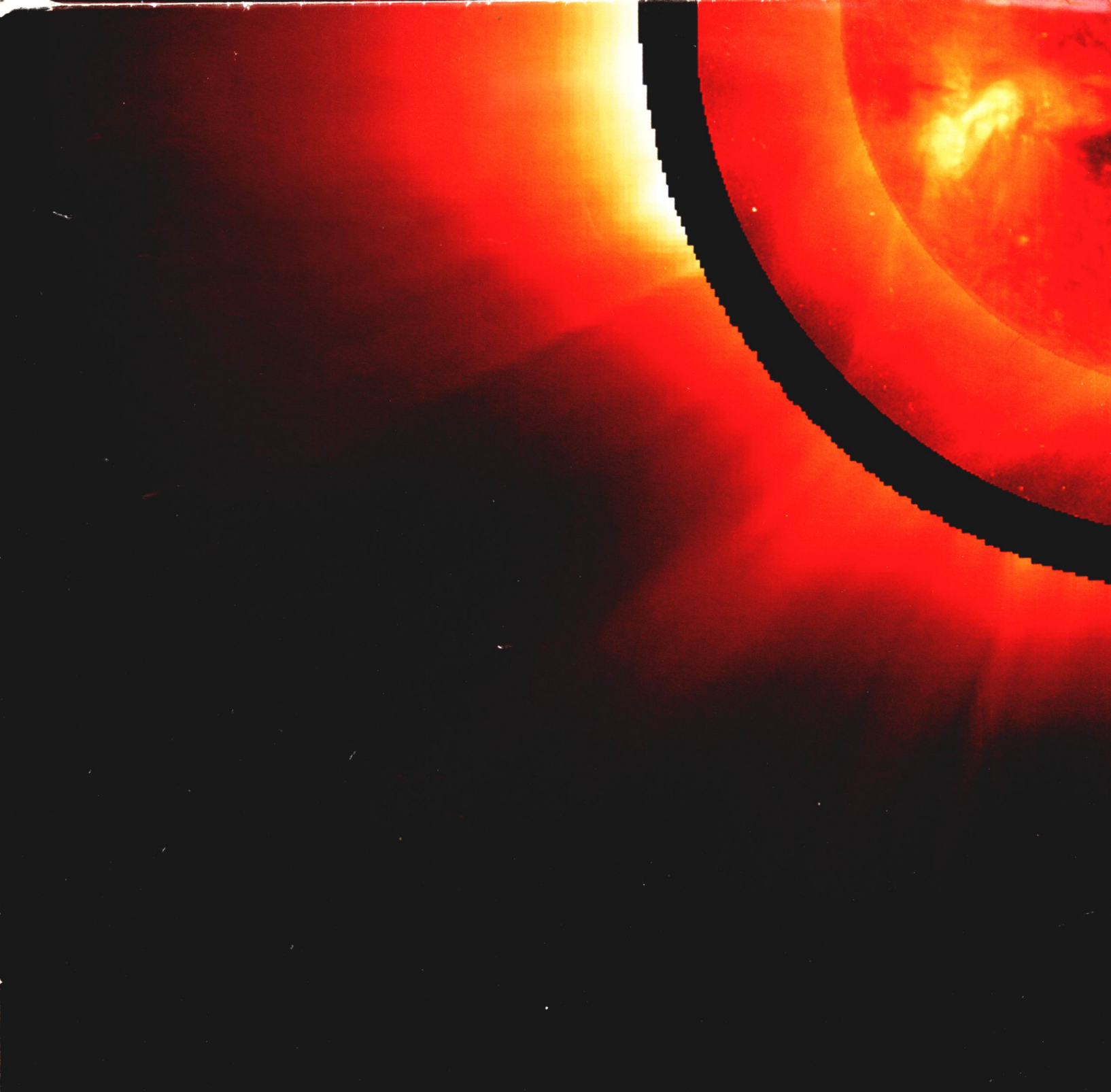
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An image of the Sun taken in ultraviolet light reveals gas at 1.5 million degrees Celsius shaped by magnetic fields. This and other data provided by SOHO have shown that the Sun is unexpectedly active, even during the quiet part of its 11 year activity cycle.

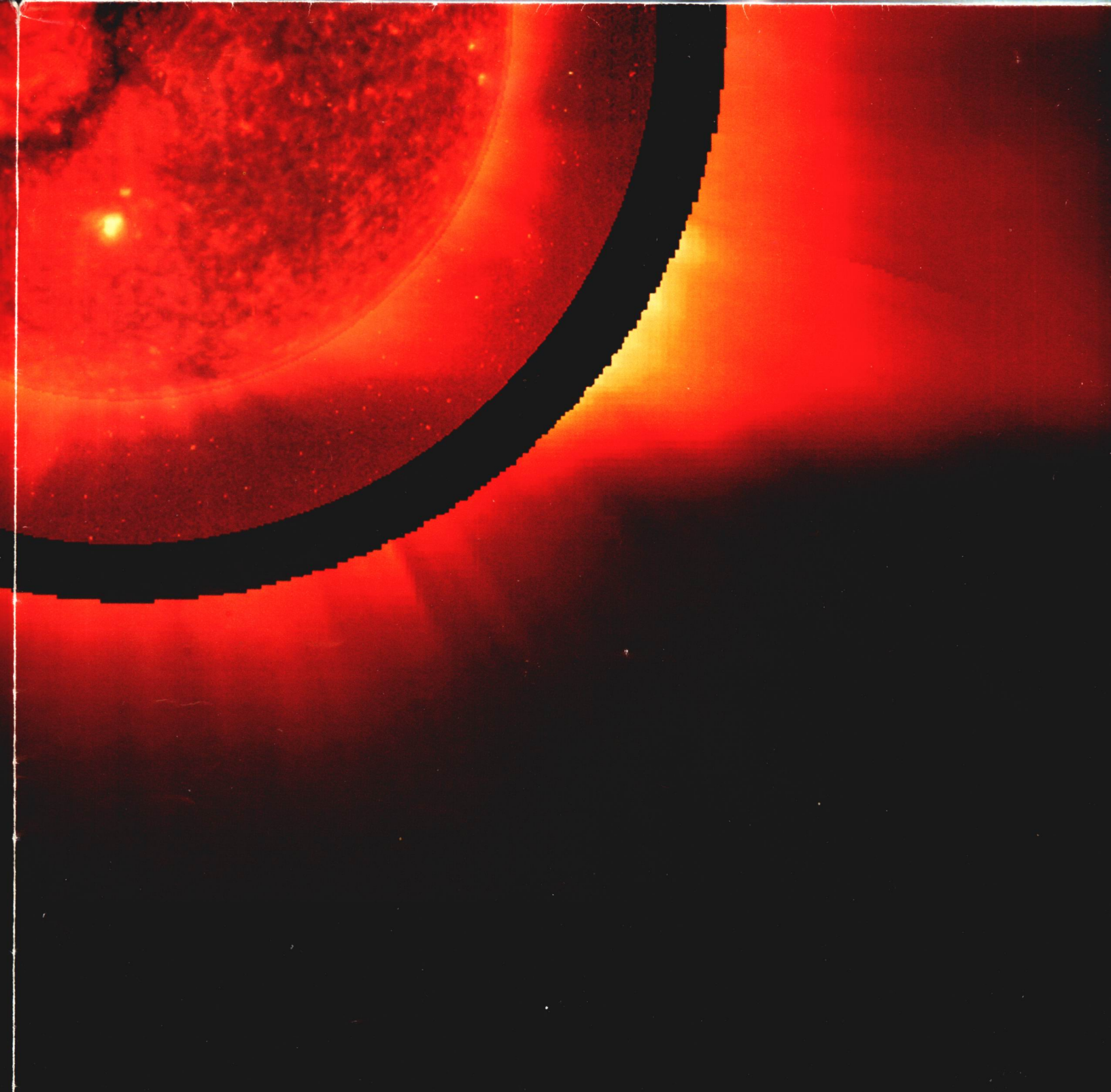






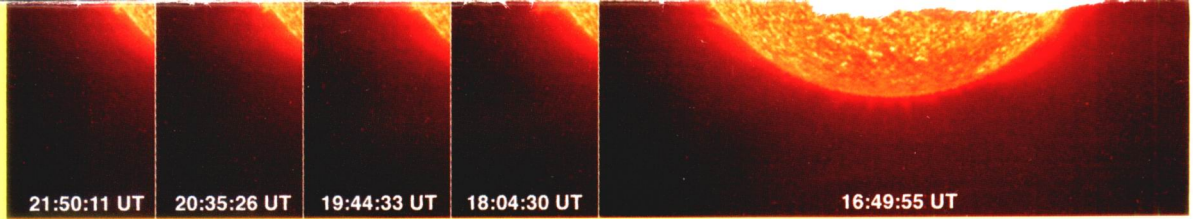
**The Sun's outer atmosphere, the corona, as it  
This composite image was taken by two instrumen  
The structures in the Sun's atmosphere are contro  
shows where the two images join) allows us to  
kilometers above the solar sur**



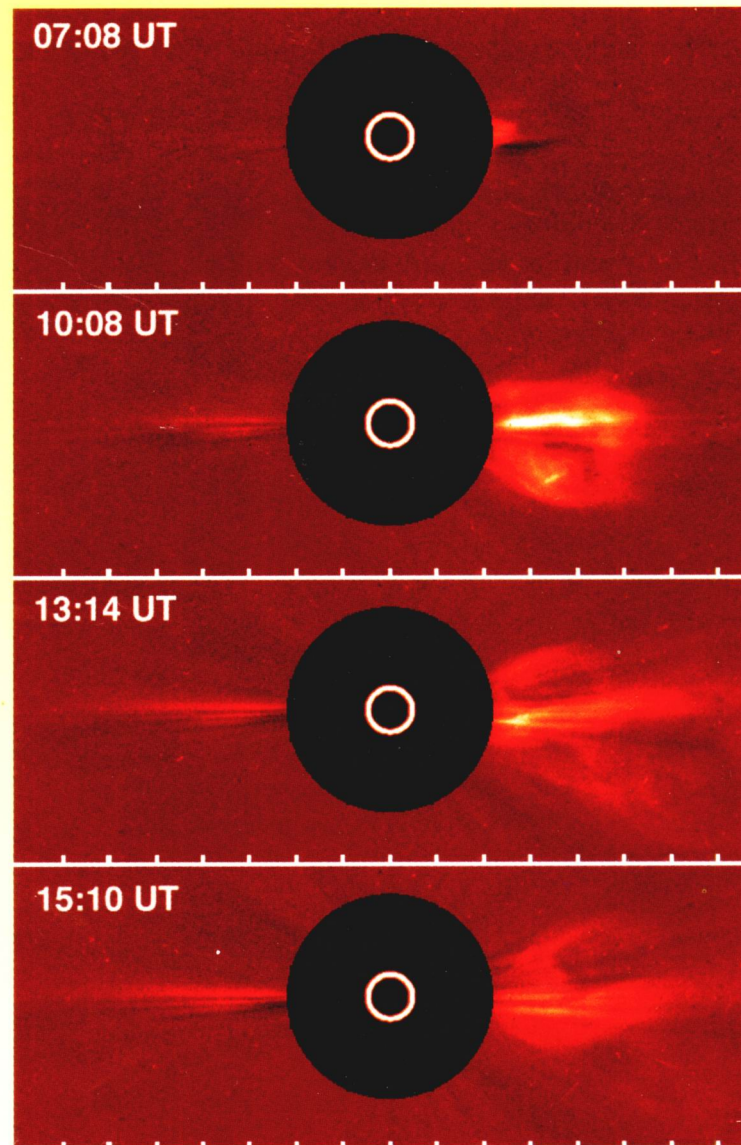


appears in ultraviolet light emitted by electrically charged atoms.  
its aboard the SOHO (Solar and Heliospheric Observatory) spacecraft.  
lled by its magnetic field. The composite image (the black circular line  
o trace these structures from the base of the corona to millions of  
face, giving scientists a truly new view of the Sun.





This sequence of images of the Sun taken at a different ultraviolet wavelength shows a blob of 60,000-degrees C gas, over 130,000 km long, being ejected at a speed of at least 24,000 km per hour.



A large Coronal Mass Ejection (CME) as recorded by a SOHO coronagraph. CMEs are clouds of million degree C gases ejected from the Sun at hundreds of km per second. When they reach the Earth in 2.5 to 5 days, they can disturb the Earth's magnetic field and interfere with electrical and navigational equipment. The CME is visible because the bright light of the solar disk has been blocked. The white circle in the center shows size and location of the Sun's surface.